DETECTION AND CHARACTERISATION OF RESIDUAL MINING SUBSIDENCE USING DINSAR AND PS INTERFEROMETRY: APPLICATION TO NORD/PAS-DE-CALAIS COALBASIN (NORTHERN FRANCE)

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ABSTRACT

The extraction of underground resources induces subsidence on the surface. The soil deformations often create disorders in structures and infrastructures. In the case of coal mining, the major part of subsidence occurs during active mine, and the residual subsidence may cover a long period of about 5 years after the end of the mining works. The amplitude of this residual subsidence is usually very small compared to the total subsidence. "Charbonnages de France" is in charge of the monitoring of the area of Nord/Pas-de-Calais (France), known for its important mining resources at depth. So, despite the fact that the exploitation of mine in this area is completed since 1992, Charbonnages de France is still monitoring the surface with high precision levelling for surveying potential displacements evolution. This traditional method presents many disadvantages like expensive cost or low extent; the interferometry technique could present a serious help to quantify the residual subsidence.

In this study, both differential SAR Interferometry (DINSAR) and Persistent Scatterer Interferometry (PSI) are used to estimate deformation during a 12 years period (1992 to 2004) after the end of exploitation. 88 ERS scenes, distributed on two adjacent tracks, are processed, using DIAPASON software for DINSAR and GAMMA-IPTA for PSI. The area undergoes high temporal decorrelation due to the high amount of vegetation. The evaluation of atmospheric artefacts is also difficult in this area. Nevertheless, deformations are well detected: they present low amplitude with a maximum rate of only 1 cm/y during 5 to 7 years after the end of the exploitation.

The results obtained by interferometry are compared to traditional levelling measurements, and show a good agreement. A robust methodology can be developed to use interferometry for surveying soil above deep abandoned coalmines.

1. DESCRIPTION OF THE STUDY AREA

The north of France is known for its important mining resources exploited since 1720 to the end of 1990 on the Nord/Pas-de-Calais coal basin. It extends on 100 kilometres from east to west, from the Belgium boundary, and is only 15 kilometres width. The carboniferous coal deposits are trapped in between hercynian thrusts sheets buried below the cretaceous chalk 125 meters thick cover. Although the exploitation methods changed trough time, longwall with back filling and later with goaf caving method was generalized after the 1950's. The latter causes the most important deformations during the exploitation phase and a maximum of only 10% of the total deformation remains subsequently and constitutes the subsidence residual phase (Louarti, 1981; Wojtkowiak, 1995; Piguet *et al.*, 1999) (Fig. 1). The goal of this study is to use the interferometric methods to focus on the residual phase deformation between 1991 and 2004 within the framework of the post-mining survey under the auspices of Charbonnages de France. Indeed, this area presents important issues due to an important demographic density (2 millions inhabitants) in particular with the Lens and Valenciennes conurbations. In this paper, we will in first analyse the existing data, then we will present interferometric treatments and finally compare them with the traditional methods of levelling.

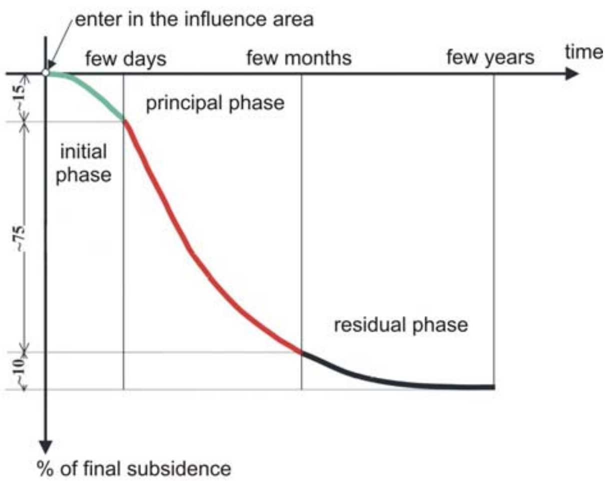

Figure 1: The three different phases of the subsidence according to a considered point at the surface.

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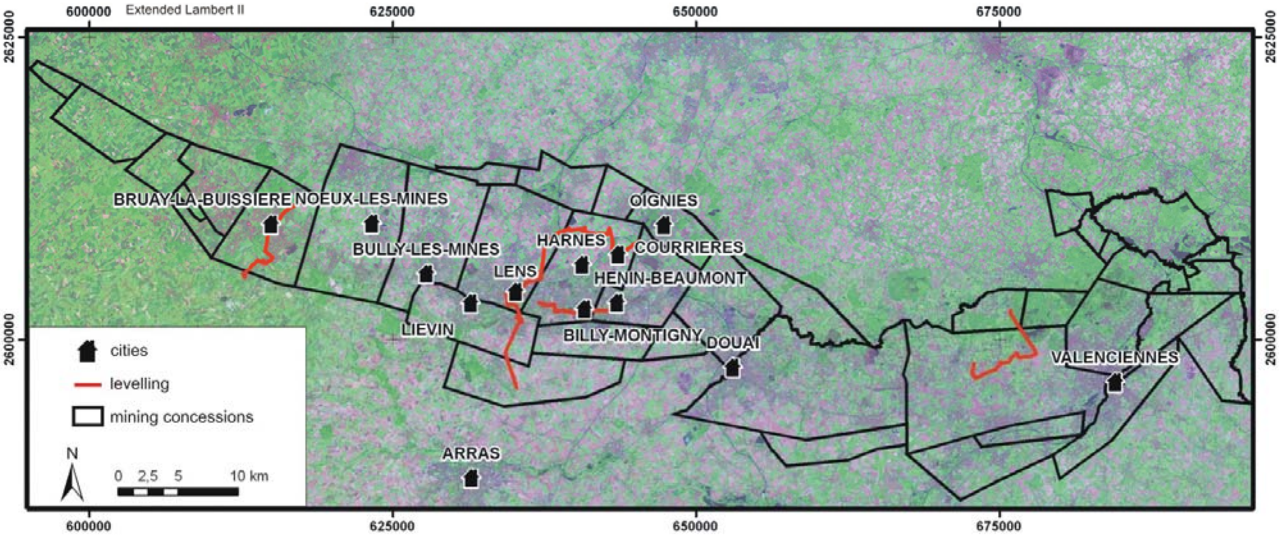


Figure 2: Levelling monitoring of the Nord/Pas-de-Calais coalbasin.

1.1. High precision levelling data

Since 1991, Charbonnages de France established five high precision levelling lines monitored by the French National Geographic Institute (IGN). Three zones were then monitored initially (Wallers/Arenberg, Billy-Montigny and Estevelles/Carvin/Courrières), which were later extended to Lens and Bruay-la-Buissière in 1998 (Fig. 2).

Precise measurements are realised each year in the beginning of October, except in 1999 where two campaigns have been carried out during spring and autumn in order to reveal seasonal effects. Two years (1992 and 1995) are missing.

This precise levelling allows to identify different areas showing surface displacement and some depressions are clearly observed. Displacements reach four centimetres for all the points of the Billy-Montigny line in eight years (Fig. 3).

Concerning the Estevelles/Carvin/Courrières line, some points with a six centimetres amplitude can be identified between 1992 and 1999, but only in the restricted area of the “Cité Saint Paul”.

Some points in surrection are also highlighted in particular for the line of Estevelles/Carvin/Courrières where the movements reach two centimetres for a period of seven years (92-99).

After 1999, the stabilisation of the majority of the levelling points of the three studied lines is observable. Only a few points of the “Cité Saint Paul” sector (Estevelles/Carvin/Courrières lines) still present subsidence of low amplitude (0.25 centimetres per year). Some points of the Lens and Billy-Montigny levelling lines present new displacement between 2002 and 2004 reaching an amplitude of the order of the centimeter over this period.

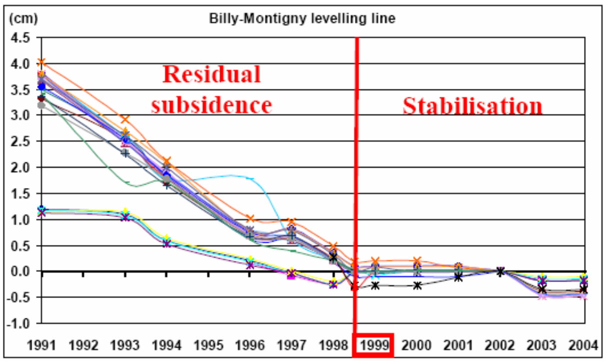


Figure 3: Example of the Billy-Montigny levelling line. The stabilisation of the residual subsidence is clearly observed after 1999.

1.2. Exploited seams cartography

Charbonnages de France provided us a complete cartography of the exploited seams on the whole basin at 300 meters below the surface. This data base also contains the years of exploitation as well as the exploited thicknesses and thus makes it possible to locate the last exploited zones and to consider the awaited compressing rate. This step was carried out during previous work undertaken by INERIS (Degas, 2001) and allowed to draw up cartography of the zones which are most sensitive to residual subsidence.

2. DIFFERENTIAL AND PERSISTENT SCATERRERS INTERFEROMETRY

Since the beginning of the 1990’s, the utility and the effectiveness of the radar interferometry treatments for the monitoring of the topographic surface movements, in particular in mining areas, were shown with many recoveries (Carnec *et al.*, 2000; Raucoules *et al.*, 2002;

Raucoules *et al.*, 2003; 2003; Colesanti *et al.*, 2005). Two methods are used here for this study: differential interferometry radar (DInSAR) and Persistent Scatterer Interferometry (PSI), with *CNES Diapason* and *GAMMA Remote Sensing IPTA* softwares respectively. The satellite data used in this study are coming for ERS-1 and ERS-2: 88 scenes distributed on two frames are available with an approximately three months periodicity between 1992 and 2002. Unfortunately, due to the zero-gyro mode of ERS-2, interferometric processing could not be carried out after 1999.

2.1. DINSAR and PSI results

According to the last areas exploited, we focused this study on the center of the coal basin, around the important conurbation of Lens. In addition, this area presents the advantages to be monitored by three levelling lines. The major of studied area presented important temporal decorrelation difficulties. The presence of an important part of fields and forests as well as a low urban density leads to low coherence which limits the use of DInSAR. Nevertheless, the area of Lens provides a quite good coherence and concentrated our attention. We thus clearly could highlight three principal zones of movements localised on the towns of Courrières, Billy-Montigny and Lens. They show a depression phase between 1992 and 1996 with a deformation of about four centimetres over this period, corresponding to one centimetre per year velocity (Fig. 4).

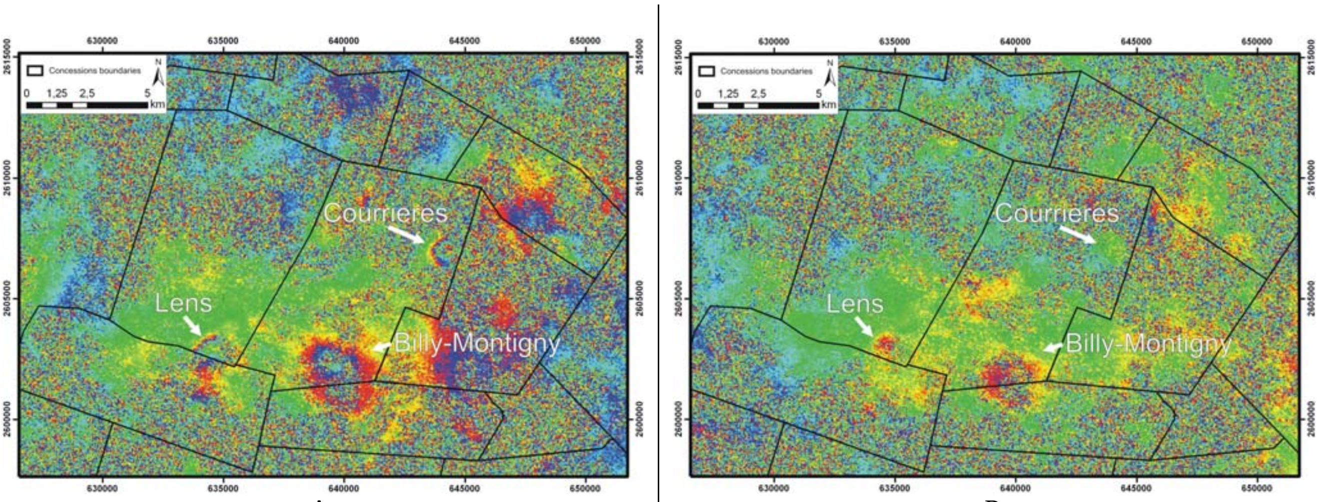
between 1996 and 1999 (end of the exploited data). The subsidence rate of these areas, initially of about 1 centimetre per year, decreases after 1996 and reaches 0.5 centimetres per year. Thus, the total subsidence is then of about 6 centimetres over the whole 1992 to 1999 period.

The PSI method allows to confirm the results obtained by DInSAR and to identify more precisely the moving areas. Indeed, although the three zones quoted previously are again identified and present the same order of magnitude of deformations, a new area at the North of the Courrières city appears active. Located in the "Cité Saint-Paul", this one shows an average velocitiy of about 1 centimetre per year all along the considered time period (Fig. 5).

3. DISCUSSION

3.1. Methods comparison

DInSAR measurements are compared to precise levelling data provided by Charbonnages de France in areas where both are available. This could be carried out only for the zones of Courrières and Billy-Montigny, because the levelling of Lens becomes available only since 1999. They are in good agreement, and show same areas of displacements with the same order of amplitude. On Courrières area, DInSAR method provides clear results on the city and highlights a subsidence of about 1 centimetre per year. But, on the other hand, it does not provide any result for the "Cité Saint-Paul" due to a too low temporal coherence.



A. B.

Figure 4: Identification of subsiding areas with DINSAR. A.: 6623-25504 interferogram (21/10/1992-31/05/1996) highlighting three principal subsidence areas. B.: 8837-21362 interferogram (28/12/1996-22/05/1996) showing only two subsidence areas still active after 1996.

After 1996, no interferometric fringes can be observed on the Courrières area. But we can't exclude that small movements remain with amplitude under the detection threshold of the method. On the other hand, both zones of Lens and Billy-Montigny still present movements

However, some PS pixels have been found in the "Cité Saint Paul", and can be compared with levelling points in a 150 metres neighbourhood. They present very good agreement and proved the effectiveness of this method in low temporal coherence areas (Fig. 6).

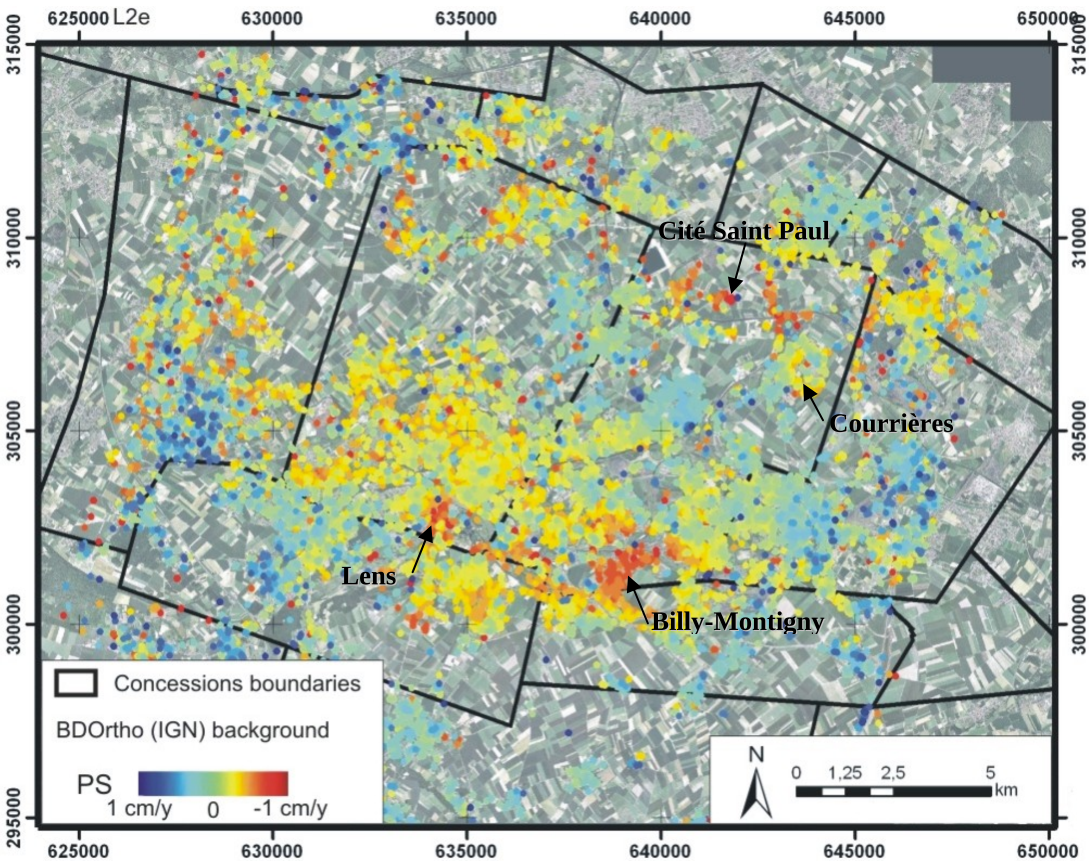
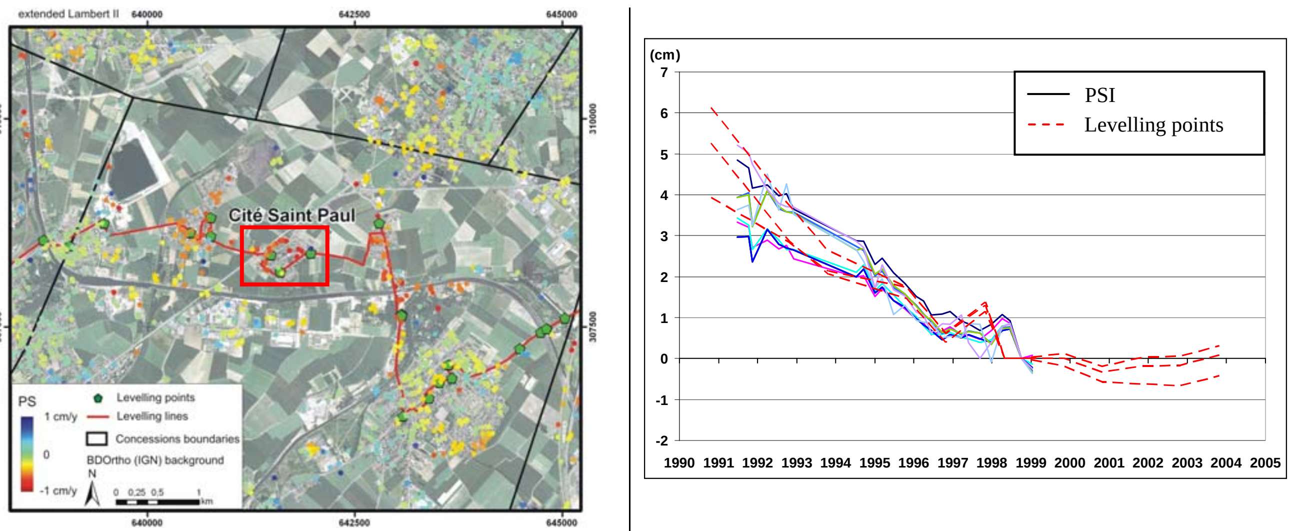


Figure 5: PS average subsidence rate between 1992 and 1999.



A. B.

Figure 6: Comparison between PS displacements and levelling monitoring in the "Cité Saint Paul" area for PS closer than 150m of the levelling point. A.: Localisation of the "Cité Saint Paul" area and considered data (red square). B.: Comparison of PS and levelling results where dashed lines represent the levelling points and continued lines, the PS.

Concerning the results for the Billy-Montigny area, we observed depressions of the same order of magnitude for the two methods allowing the validation of the interferometric results in this quite urbanised region.

3.2. Interferograms analysis

After unwrapping, vertical displacements maps are obtained. Spatial profiles, calculated on a 11 pixels large band allow to compare the different subsidence area shapes through time (Fig.7). We can then highlight important differences between Lens and Billy-Montigny behaviour. Indeed, the Lens subsidence area shows some quite abrupt slopes at the difference of Billy-Montigny which looks smoother. These differences may be due to different exploitation types and extent. On the other hand, using numerous profiles allows to realize three-dimensional visualization. The latter is very interesting to clearly visualize the shapes and spatial extent of the subsidence areas and confirm the more smooth slopes of the Billy-Montigny area according to the Lens one.

A.

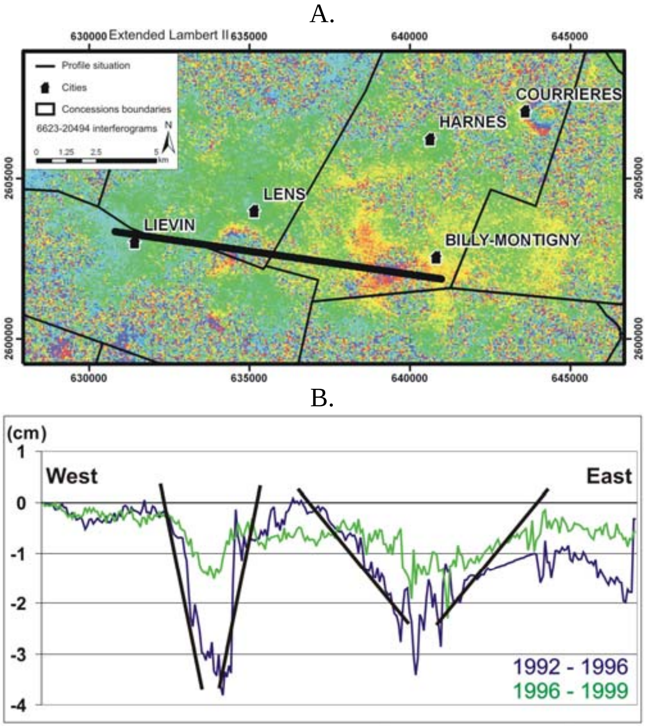


Figure 7: Localisation (A) of the profiles (B) obtained from the unwrapping interferograms for two different time period (1992-1996 in blue; 1996-1999 in green)

4. CONCLUSION

The precise levelling method is traditionally used for low topographic surface movements monitoring. It already proved its ability to monitor residual phase deformation and provides very precise order of magnitude. However, this method is limited by its small spatial extent and its expensive cost. DInSAR and PS interferometry offer new possibilities as both gives access to displacements that are of the same orders of magnitude than levelling and allow to investigate areas of larger spatial extension. It is also possible to take benefit from the ERS archive, with images acquired since 1992. In addition, the description of a new moving zone by the PSI shows that this method is particularly effective in areas of low temporal correlation where DInSAR fails and is then complementary. The realisation of profiles, velocity and displacement maps has moreover provided a great help for the analysis of the observed phenomenon.

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